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A Cellular Radio Communications System

10 Field of Invention

The present invention relates to a cellular radio communication system. In particular the present invention relates to a broadband wireless access system suitable for the delivery of multi-media services.

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Background of Invention

There is a growing demand for broadband wireless access systems which can deliver the high data rates required for the provision of multi-media services. Such wireless access systems operate within licensed frequency bands. Accordingly, these systems are continually developing to carry more data across the limited frequency band allocated to them. Pressure for this development is two fold. Firstly, there is increased demand for multi-media services from subscribers to the system. Secondly, revenue for the network operator will increase as billing is calculated on a per byte of information delivered basis as opposed to on a timed basis.

The performance of wireless access communication systems is prone to dynamic degradation, ie. time variant degradation, due to changing environmental conditions. Wireless transmissions in the frequency range

from 10 to 50 GHz are particularly prone to dynamic degradation resulting from rain and from the growth and movement of foliage located in the path of the transmission. Figure 1 shows the attenuation of a 30GHz signal in dB per kilometre due to rainfall against the percentage of time that such rainfall occurs within climate zone 'F' which zone covers the UK.

This type of dynamic degradation has been taken account of in existing wireless access systems by designing the systems for operation in worst case environmental conditions. This has been achieved by the use of robust modulation schemes such as QPSK (Quadrature Phase Shift Keying), also known as 4-QAM (Quadrature Amplitude Modulation) which deliver low BERs (bit error rates) of the order of 10^{-9} , ie. one incorrect bit per 10^9 bits transmitted, in poor environmental conditions. However, designing such systems for worst case environmental conditions in this way results in low rates of data transmission.

As can be seen from Figure 1, for the majority of time transmission conditions are good. Adaptive modulation techniques have been proposed which enable higher data rates to be achieved by the use of 16-QAM or 64-QAM modulation schemes when the transmission conditions across a wireless link are improved or where the distance over which the link extends is relatively low. In this way the rate of data transmission within a limited frequency band can be improved.

In known cellular wireless access system a frequency plan is implemented over a geographical area covered by the system. The frequency plan allocates channels within the frequency band to localised cells and due to attenuation of a radio signal across the cells, the same channel can be re-used within other cells in the frequency plan. The aim is to maximise frequency re-use without causing interference between parts of the frequency plan which use the same channels. Generally, a base station is associated with a cell to transmit radio frequency signals to all end users or

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Statement of Invention

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The different modulation scheme and forward error correction coding level pairs are preferably dynamically allocated depending on the quality of the transmission links. Thus, when the quality of a transmission link is good a high symbol modulation scheme, such as 64-QAM can be allocated in order to achieve a high data rate at the required bit error rate. When the quality of the transmission link is reduced a lower symbol modulation scheme such as QPSK can be used to achieve the bit error rate at the cost of a reduced data rate across the transmission link. Although the use of forward error correction coding inherently reduces data rates, the dynamic allocation of the forward error correction coding levels enables higher symbol modulation schemes to be used for poorer transmission links while still maintaining the required standard of bit error rate to enable an overall increase in data rates achievable over a range of quality of transmission links. Preferably, the quality of transmission links are periodically monitored.

25 The system may allocate a default modulation scheme and/or forward error correction coding level for each transmission link for use when a call is initiated over the transmission link. The default modulation scheme will generally be the highest symbol modulation scheme or optimum modulation scheme/coding level pair that can be used for that transmission link in poor environmental conditions while still maintaining the required bit error rate.

30 Preferably the system comprises means for adjusting the power of the transmission links dependent on the level of traffic over the transmission

5 dependent on the change in the level of forward error correction coding to maintain the predetermined bit error rate. Thus, if a particular cell comprising the base station and the end user terminals does not need to utilise the total bandwidth of its transmission links, the level of coding can be increased to use up the remaining bandwidth which enables the power of the transmission links to be reduced while still achieving the required bit error rate. The whole bandwidth allocated to the cell is used but at a lower power level. The fact that the cell is transmitting at a lower power level means that it is generating less interference in neighbouring cells. This enables the neighbouring cells to support a higher data rate if they need to. Thus, those cells that do not require maximum data throughput can effectively release bandwidth to neighbouring cells by using the minimum level of power associated with achieving the required bit error rate.

According to a second aspect of the present invention there is provided a cellular radio communication system for transmitting blocks of data over transmission links, comprising:

30 a data storage means for storing sets of modulation
scheme and forward error correction coding level pairs
which give an optimum data rate at a predetermined bit

means for monitoring the quality of a transmission link;

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means for applying a modulation scheme and forward error correction coding level to the blocks of data in

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means are provided for increasing the level of forward error correction coding allocated to the transmission links so as to use the bandwidth of the transmission links and means are provided for reducing the power of the transmission links dependent on the increase in the level of forward error correction coding to maintain the predetermined bit error rate.

The present invention is particularly suited for use in broadband wireless access systems. The transmission links from the end user terminals to the base station may comprise a common medium access uplink and the transmission links from the base station to the end user terminals may comprise a broadcast downlink.

According to the present invention a block of data may comprises a header and a payload and means are provided for storing a default modulation scheme suitable for the or each transmission link in poor environmental conditions and the means for allocating a modulation scheme to the blocks of data transmitted over the transmission link allocates the default modulation scheme to the headers of the blocks of data.

According to a fifth aspect of the present invention there is provided a receiving unit is provided for receiving signals from at least one transmission link, which signals carry blocks of data where each block comprises a payload and a header containing information about the modulation scheme applied to the payload wherein the receiving unit comprises:

- a receiving antenna means;
- a downconverter means for downconverting a radio frequency signal received by the antenna means to an intermediate frequency signal;
- an IQ demodulator means for demodulating the intermediate frequency signal;

a recovery means for receiving the output of the IQ demodulator and for recovering the payload modulation scheme from each header;

an IQ signal detection block for receiving the output of the IQ demodulator, the IQ signal detection block comprising:

a first arm for detecting an IQ demodulated signal from a first modulation scheme;

a second arm for detecting an IQ demodulated signal from a second modulation scheme; and

switching means for switching the output from the IQ demodulator through one or the other of the arms dependent on the payload modulation scheme recovered by the recovery means.

According to a sixth aspect of the present invention there is provided a transmitting unit for transmitting signals over at least one transmission link, which signals carry blocks of data wherein the transmitting unit comprises:

a database for storing modulation schemes which generate an optimum data rate at a predetermined bit error rate and symbol rate for different quality transmission links;

a processor for interrogating the database and allocating a modulation scheme to the blocks of data to be transmitted dependent on the quality of the transmission link;

an IQ signal generation means comprising:

a first arm for generating an IQ signal for a first modulation scheme;

a second arm for detecting an IQ signal for a second modulation scheme; and

switching means for switching data through one or the other of the arms dependent on the modulation scheme allocated to the data.

- 5 According to a seventh aspect of the present invention there is provided a radio frequency signal IQ modulated with blocks of data wherein a block of data comprises a header and a payload and the payload is modulated according to a higher symbol IQ modulation scheme than the header. Preferably, the header is modulated according to a QPSK
10 modulation scheme and the payload is modulated according to a 16-QAM or a 64-QAM modulation scheme.

- According to an eighth embodiment of the present invention there is provided method of operating a cellular radio communication system for
15 transmitting blocks of data over transmission links, comprising the steps of:

- storing sets of modulation scheme and forward error correction coding level pairs which give an optimum data rate at a predetermined bit error rate and a predetermined
20 symbol rate for different quality transmission links;
monitoring the quality of a transmission link;
interrogating the database and allocating a modulation scheme and forward error correction coding level pair to the blocks of data transmitted over the link dependent on
25 the monitored quality of the transmission link; and
applying the allocated modulation scheme and forward error correction coding level to the blocks of data.

- The method has the same advantages as associated with the
30 communication system according to the first aspect of the present invention.

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Figure 6 is a graph showing the peak data rate achievable according to the present invention for varying carrier to noise interference ratios (CNIRs) for QPSK, 16-QAM and 64QAM modulation schemes assuming a signalling rate (symbol rate) of 5Mbaud;

Figure 7 shows schematically how blocks of data are assembled for transmission across a carrier according to the present invention;

5 Figures 8a and 8b show graphs of the peak data rate against the percentage change of a CPE having such a rate for a known system and a system according to the present invention respectively;

10 Figure 9 represents the IQ modulation plot for a 16-QAM modulation scheme showing the basis on which the carrier to noise and interference ratio of a carrier;

Figure 10 shows the configuration of a base station transmit path according to the present invention;

15 Figure 11 shows the configuration of a CPE receive path according to the present invention;

20 Figure 12 shows the configuration of a CPE transmit path according to the present invention; and

Figure 13 shows the configuration of a base station receive path according to the present invention.

Detailed Description of Invention

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Figure 2 shows a fixed wireless access architecture suitable for use in a cellular radio communication system according to the present invention. The architecture comprises a fixed wireless access base station (301) which can transmit radio frequency signals to a plurality of CPEs (Customer Premise Equipments) (311) within a localised area or cell. The base station has an array of antennas (309) for transmitting signals to and receiving signals from antennas (310) which form part of the CPEs (311).

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(324) are furthest away from the base station and so transmission links between these CPEs and the base station (301) use a default QPSK modulation scheme which can achieve an acceptable bit error rate of around 10^{-9} regardless of the prevailing environmental conditions. This system is designed so that it can maintain an acceptable bit error rate in the worst environmental conditions which occur less than 1% of the time. As shown in Figure 8a, if this scheme is implemented without further adaptation, just over 10% of customers receive a data rate of 25Mbits/s with a 100% probability, approximately 40% of customers receive a data rate of 13Mbits/s with a 100% probability and just under 50% of customers receive a data rate of 5Mbits/s with a 100% probability.

According to the present invention a level of FEC (forward error correction) coding and a modulation scheme is selected which provides an optimised data rate for a transmission link between a base station and a CPE in accordance with the graph shown in Figure 6 for a CNIR (carrier to noise and interference ratio) detected for that transmission link. The graph in Figure 6 is based on a constant symbol rate of 5Mbaud and a constant bit error rate of 10^{-9} . In this illustrative example the type of FEC coding used is BCH (Bose, Chaudhuri and Hocquenghem), however other code types could be used. Starting from the right of Figure 6, for a high quality transmission link having a CNIR of 35, then a 64-QAM modulation scheme can be used with no FEC coding. Moving towards the left on the 64-QAM curve of Figure 6, successive boxes marked on the curve indicate a step in the level of FEC coding, from $t = 0$ to 13. For example, for a CNIR of between 29 and 34 a level 1 FEC code (ie. $t = 1$) has to be used and for a CNIR of between 27 and 29 a level 2 FEC code has to be used to maintain a BER of 10^{-9} . Where the 64-QAM and 16-QAM plots overlap, the modulation scheme/FEC pairing which generates the highest data rate is preferentially selected. For example, for a CNIR of 25, 64-QAM modulation and a level 4 FEC code will provide the highest data rate, whereas for a CNIR of 21, 16-QAM modulation and a level 2 FEC code will provide the

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1 and Q going from -1 to 1, the positions of the symbols or constellation points are shown by an X. When a 16-QAM modulated signal is transmitted over a transmission link and then demodulated, the detected values will be spread about each constellation point due to the effects of noise and interference on the transmission link. The CNIR value is $10\log(r^2)$ where r is the RMS value.

The flow chart in Figure 4 which shows the steps in the formation and transmission of signals across the downlink, ie. from base station to the CPEs according to one embodiment of the present invention.

When a call is initiated outside of the cell to a CPE within the cell it is routed via the base station. It may for example be a data, voice, constant bit rate (CBR) or variable bit rate (VBR) call and will have associated with it a required quality of service. The term "call" is used here to cover both traditional switched connection based systems, such as ATM and connectionless systems, such as IP. Each such call is routed via the base station in accordance with a connection set up between a location outside of the cell and the customer or in accordance with packet header information (STEP i).

Each call is routed into a data transmission queue in accordance with its requested quality of service (via STEP iii). The data in each queue is partitioned into blocks and a Medium Access Control (MAC) header (72) is added to each block, as shown in the top layer of Figure 7 (STEP ii). Each block is assigned a modulation scheme and FEC coding level depending on the quality measurement made by the CPE which the block is to be sent to, which measurement is transmitted to the base station (STEP iv and v). As the call progresses the base station will receive ongoing feedback from the CPEs in the cell about the quality of the downlink and will alter the modulation and coding scheme accordingly. Each block is then partitioned into segments (74) and the appropriate FEC coding (76) is added to each

segment, as shown in the middle layer of Figure 7 (STEP vi). The blocks are then re-assembled from the segments with FEC coding added and the blocks are grouped according to their allocated modulation level as shown in the bottom or physical layer of Figure 7. These groupings of blocks form the physical payload (78) for the physical layer to which is pre-appended a physical layer header, as shown in the bottom layer of Figure 7 (STEP vii). This header is always allocated a modulation of 4-QAM (QPSK) and includes a preamble (80), a sync sequence (82) and information (84) stating the modulation and coding applied to the following physical payload (78).

10 The thus, configured data from each queue is then sent to the base station data scheduler and transmitted to the subscribers across the transmission link in an order determined by the quality of service associated with each queue (STEP viii). At the CPE the information in the physical header is recovered using QPSK and for example using a correlation code. The

15 physical payload is then recovered by demodulation using the demodulation and coding scheme set out in the physical header (STEP ix).

The flow chart in Figure 5 shows the steps in the formation and transmission of signals across the uplink, ie. from a CPE to the base station.

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Where a call is initiated by a CPE a request will be made by the CPE to the base station. The call may for example be a data, voice, constant bit rate (CBR) or variable bit rate (VBR) call and will have associated with it a required quality of service. Again, the term "call" is used here to cover both

25 traditional switched connection based system, such as ATM or connectionless system, such as IP. Each such call is routed via the base station in accordance with a connection set up between the customer and a location outside of the cell or in accordance with packet header information

30 (STEP i). The request will be made by the CPE, for example on a contention basis, using a default modulation level. The default modulation level may be associated with the CPE's location with respect to the base

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detection and for example using correlation codes. The physical payload is then recovered by demodulation using a demodulation and coding scheme as set out in the physical header (STEP ix).

- 5 Using adaptive modulation and FEC coding as described above results in a more efficient use of bandwidth within a cell. As shown in Figure 8b, around over 80% of customers will receive a data rate of 25Mbps/s with a greater than 95% probability.
- 10 Figures 10 to 13 show a suitable configuration of a base station and CPE for use in the cellular radio communication system according to the present invention. In addition to the method described in relation to Figures 4 and 5, the base station and CPE configurations shown in Figures 10 to 13 operate a power control function.

Figure 10 shows the configuration of the base station transmit path. The blocks of data with the MAC headers applied (as shown in the top layer of Figure 7 and as generated by STEP ii of Figure 4) is input into the FEC and physical layer bit stream assembly means (100). A level of FEC coding is applied to the blocks of data by the means (100) (as described in STEPs iv and vi of Figure 4) in response to a FEC coding level input into the means (100) by the modulation/power controller (102). The FEC coding level, modulation scheme and signal power to be applied at any time to the data blocks passing through the base station transmit path is fed to the modulation/power controller by the base station processor (104).

The base station processor (104) will receive the CNIR measurements from the CPEs in the cell and will interrogate a look up table or database (105) embodying the information in the graph of Figure 6 and will select a coding (hereafter referred to as default coding) and a modulation scheme for the data blocks in accordance with the CNIR measurement from their destination CPE. The base station processor also carries out a power

switch to a position such that the data block passes through the required arm. The IQ signal conversion block (108) generates the voltage amplitudes that form the I and Q signals required to represent each symbol in a data block dependent on the modulation scheme to be applied to that data block. The I and Q signals are then input into the IQ modulator (120), after being filtered by a finite impulse response (FIR) shaping filter (118).

For example, where a data block requires QPSK modulation, then in response to the signal input from the controller (102) the switch means (116a,116b) will switch to the position shown in Figure 10 and the IQ signal conversion arm (114) will generate QPSK I and Q signals and the output will be passed through the IQ modulator (120) via the filter (118). The IQ modulator will generate a carrier wave modulated with 4 states. Where a data block requires 16-QAM modulation, then in response to the signal input from the controller (102) the switch means (116a,116b) will switch so that the 16-QAM arm (112) will generate 16-QAM I and Q signals which will be passed to the IQ modulator (120) via the filter (118). The IQ modulator will generate a carrier wave modulated with 16 states. Where a data block requires 64-QAM modulation, then in response to the signal input from the controller (102) the switch means (116a,116b) will switch so that the 64-QAM arm (110) will generate 64-QAM I and Q signals which will be passed to the IQ modulator via the filter (118). The IQ modulator will generate a carrier wave modulated with 64 states.

The signal output from the IQ modulator is then upconverted and amplified by amplifier (122) and transmitted over the downlink via antenna (309). The level of power generated by the amplifier (122) is dependent on an input from the modulation/power controller (102) dependent on the volume of data blocks passing through the base station. The level of power to be applied to a signal output from the base station transmit path at any time will be calculated by the base station processor (104), as indicated above and input into the amplifier (122) via the controller (102).

Figure 11 shows the CPE receive path. The CPE receives signals transmitted over the downlink via the antenna (310) and the received signal is downconverted in the rf stages (124) and demodulated in IQ demodulator (126). The output from the demodulator is input into a header information recovery means (128), which detects QPSK signals and recovers the header information, for example by applying correlation coding. The header information will include the modulation scheme and FEC coding level required to recover the data in the payload associated with the header. The output of the demodulator is also input into an IQ signal detection block (130) via a FIR matched pulse shaping filter (132). The recovery means (128) recovers the modulation scheme associated with the incoming payload and actuates switching means (134a,134b) to switch the data output from the IQ modulator through the correct arm of the IQ signal detection block. The arm (132) is arranged to detect IQ signals sent using a 64-QAM modulation scheme, the arm (135) is arranged to detect IQ signals sent using a 16-QAM modulation scheme and the arm (136) is arranged to detect IQ signals using a QPSK modulation scheme.

For example where a physical payload sent using a QPSK modulation scheme is received and demodulated the recovery means (128) detects this and switches the switching means (134a,134b) to the position shown in Figure 11, so that the payload is passed through the arm (136) of the IQ signal detection block (130). Where a physical payload sent using a 16-QAM modulation scheme is received and demodulated the recovery means (128) detects this and switches the switching means (134a,134b) so that the payload is passed through the arm (135) of the IQ signal detection block (130). Where a physical payload sent using a 64-QAM modulation scheme is received and demodulated the recovery means (128) detects this and switches the switching means (134a,134b) so that the payload is passed through the arm (132) of the IQ signal detection block (130).

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data block requires 16-QAM modulation, then in response to the signal input from the controller (202) the switch means (216a,216b) will switch so that the 16-QAM arm (212) will generate 16-QAM I and Q signals which will be passed to the IQ modulator (220) via the filter (218). The IQ modulator will generate a carrier wave modulated with 16 states. Where a data block requires 64-QAM modulation, then in response to the signal input from the controller (202) the switch means (216a,216b) will switch so that the 64-QAM arm (210) will generate 64-QAM I and Q signals which will be passed to the IQ modulator via the filter (218). The IQ modulator will generate a carrier wave modulated with 64 states.

The signal output from the IQ modulator is then upconverted and amplified by amplifier (222) and transmitted over the uplink via antenna (310). The level of power generated by the amplifier (222) is dependent on an input from the modulation/power controller (202) dependent on the volume of data blocks at that time being transmitted on the uplink. The level of power to be applied to a signal output from the CPE transmit path at any time will be set by the CPE processor (204) and input into the amplifier (222) via the controller (202).

Figure 13 shows the base station receive path. The base station receives signals transmitted over the uplink via the antenna (309) and the received signal is downconverted in the rf stages (224) and demodulated in IQ demodulator (226). The output from the demodulator is input into a header information recovery means (228), which detects QPSK IQ signals and recovers the header information, for example by applying correlation coding. The header information will include the modulation scheme and FEC coding level required to recover the data in the payload associated with the header. The output of the demodulator is also input into an IQ signal detection block (230) via a FIR matched pulse shaping filter (232). The recovery means (228) recovers the modulation scheme associated with the incoming payload and actuates switching means (234a,234b) to switch

the data output from the IQ modulator through the correct arm of the IQ signal detection block. The arm (232) is arranged to detect IQ signals sent using a 64-QAM modulation scheme, the arm (235) is arranged to detect IQ signals sent using a 16-QAM modulation scheme and the arm (236) is
5 arranged to detect IQ signals using a QPSK modulation scheme.

For example where a physical payload sent using a QPSK modulation scheme is received and demodulated the recovery means (228) detects this and switches the switching means (234a,234b) to the position shown in
10 Figure 11, so that the payload is passed through the arm (236) of the IQ signal detection block (230). Where a physical payload sent using a 16-QAM modulation scheme is received and demodulated the recovery means (228) detects this and switches the switching means (234a,234b) so that
15 the payload is passed through the arm (235) of the IQ signal detection block (230). Where a physical payload sent using a 64-QAM modulation scheme is received and demodulated the recovery means (228) detects this and switches the switching means (234a,234b) so that the payload is passed through the arm (232) of the IQ signal detection block (230).

20 The output from the IQ signal detection block (230) is input into a vector error detection means (238). This measures the quality of the uplink and then passes this information into the base station return path for transmission back to the relevant CPE for use by the CPE processor (204).

25 The output from the IQ signal detection block is also passed to the symbol to bit conversion means (240). The data block output from the means (240) is decoded in decoding means (242) using the FEC coding level for that data block which is input from the recovery means (228).